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Yield and carbon sequestration of pigeon pea at different environments in Bangladesh

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Abstract

Pigeon pea is a multi-purpose species for agroforestry systems and subsistence agriculture especially the ability to survive with poor soil and little water and to recover from the losses caused by various biotic and abiotic stresses Therefore, this experiment was executed to find out the performance of four pigeon pea genotypes for yield and yield contributing characters, stability and carbon sequestration across different environments of Bangladesh. This experiment was operated under three different locations viz. Gazipur, Sylhet and Madaripur during the year 2018-2019. and The experimental materials comprised of four pigeon pea genotypes namely G1= BPP1502, G2 =BPP1503, G3 = BPP1504 and G4 = BPP1505 and was conducted in randomized complete block design with three replications in each environment. Significant differences were observed for all the genotypes of pigeon pea against number of branches/plant, pods/plant, seeds/pod, plant height, breadth, stem diameter and hundreds seeds weight among the environments. It was observed that the highest plant height (103.33 cm) of pigeon pea genotype was found in BPP1505 at Gazipur. BPP1504 was produced highest no of pods/plant (188.00) and hundred seed weight (9.10 gm) at Gazipur. Carbon sequestration per plant of pigeon pea (7.63 Ibs) and carbon sequestration per year (15.23 Ibs) both were highest in BPP1505 at Gazipur and lowest was found in BPP1503 at Sylhet. For stability of performance across environments, BPP1504 and BPP1505 were identified as most stable genotypes and BPP1502 and BPP1503 were found least stable. On the basis of both stable performance and mean seed yield across environments, the GGE biplot ranked genotype of pigeon pea, BPP1504 as the best among all, followed by BPP1505 while the rest of the genotypes were identified as inferior. Gazipur was identified as the most representative environment and highly discriminative as compared to the others.

Keywords: Yield; Carbon sequestration; Agroforestry system; GGE biplot; Genotypes; Pigeon pea

1. Introduction

Pigeon pea [*Cajanus cajan (L.) Millsp*.] is one of the major grain legume grown in the tropics and subtropics and considered as a minor pulse crop in Bangladesh which is mainly grown in the northwestern part of the country (Virmani *et al*., 1991). It can survive for a period of 3-5 years as a perennial shrub but it is normally cultivated as an annual crop. Perennial pigeon pea is receiving considerable attention in India as a multi-purpose species for agroforestry systems. In Agroforestry system there is a high potentiality of pigeon pea to bring under commercial cultivation as a intercrop with tree which is a main component as it provides the three most important services of agroforestry system namely: food, fuel and fodder (3F) along with its diversified benefits. It is the best versatile food legume, span over a wide area of the world with diversified uses and also benchmark with “sustainable agriculture” with enormous existing wild diversity, India is considered to be the “hot spot” and center of origin for pigeon pea (Van der Maesen, 1990). It is well known as finest nitrogen fixer and nutrient re-cycler (Graham and Vance, 2003; Srivastava *et al*., 2012). Besides its primary use as food, it can also be used as forage, fodder, fuel and medicine. As food, the pods whether consumed as green pea or dry grain consists of 20-22% protein, which plays a vital role in meeting the protein needs of a vegetarian

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population (Singh *et al*., 1990, Saxena, 2009). Most parts of Asia and Middle-eastern countries are the major market for good-quality pigeon peas for human consumption.

Pigeon pea is well known to produce more nitrogen per unit of plant biomass than most other legumes and can nodulate in most soils although it produces fewer nodules than any other legumes (Onim,1987). The crop is deep-rooted, so their ability to release more phosphates means that valuable nutrients are being brought up from the deeper soil layers. The release of phosphorous benefits not only the crop, but also the subsequent crops grown in the same field (Ae *et al.,* 1990). It is also considered to be tolerant to low and high temperatures. Because of these unique characteristics of pigeon pea, it is recognized as an important crop for subsistence agriculture especially so due to its drought tolerance and ability to recover from the losses caused by various biotic and abiotic stresses. In addition, the leaves of this plant can also be used as food for the silkworm (Duke, 1981) and it can also be a substitute for alfalfa in animal feed formulations. The need to substitute fishmeal in animal feed has necessitated the use of plant derived feed stuffs. Since pigeon pea has strong woody stems that grow up to 4m tall and branch freely, its spindly stalks are extensively used as a cooking fuel in energy short villages of several African countries and in India, Nepal and Sri Lanka. In the lac growing areas of China after harvesting the lac resin, pigeon pea plants are chopped and dried for fuel use. The crop produces about 6 t/ha of fuel wood (Zhenghong and Fuji, 1997). Pigeon pea offers the benefits of improving long-term soil quality and fertility when used as green manure (Onim *et al.,* 1990), cover crop (Bodner *et al*., 2007) or alley crop (Mapa and Gunasena, 1995).

A major constraint to the adoption of agroforestry systems in the semi-arid tropics is the severe competition between trees and crops for environmental resources. Pigeon pea can adapt to a wide range of soil types from gravely stones to heavy clay loams of close texture and high moisture content provided there is no standing water on the soil surface or excessive soil salinity. Extensive ground cover of pigeon pea prevents soil erosion, serves as windbreak, hedge, encourages filtration, minimizes sedimentation and smothers weeds. Traditional varieties are highly sensitive to photoperiod (McPherson *et al*., 1985) and they take about 175 to 280 days to reach maturity.

Fortunately, the loss of Soil organic carbon (SOC) can be slowed down by implementing crop management practices such as conservation tillage (Lal, 2004b; Puget and Lal, 2005), converting degraded arable land to perennial grassland (Gentile *et al*., 2005), using diverse rotations, and introducing legume and grass mixtures into the rotation (Lal, 2004c). Therefore, pigeon pea a tall woody shrub with huge branching as a legume crop has the ability to sequester carbon dioxide from atmosphere and plays a great role in stocking carbon in soil.

In Bangladesh, pigeon pea (Arhar) is mostly cultivated in Kushtia, Rangpur, Dinajpur, and Jessore districts. Total acreage of its cultivation is about 5,215 and the annual production is about 1,005 m tons (Banglapedia, 2004). Some short duration lines of pigeon pea were tested in the northern part of the country, but found promising only as intercrop (BARI, 1990). In the southern part of Bangladesh, where winter temperature remains warm enough to support the crop growth, less photosensitive and short duration pigeon pea can be introduced in transplanted aman-fallow cropping system. In the hilly areas of south-eastern part of Bangladesh also, the crop may potentially be grown during the post-rainy season.

Although Bangladesh has suitable land and friendly environment for pulse cultivation, it is heavily imported every year as the domestic production of pulse cannot address the quantity demanded domestically. Considering the above circumstances, pulse production should be increased rapidly to improve the national nutritional status along with less outflow of precious foreign currency. Pulses are in Bangladesh generally called as poor's men protein. But in these days we cannot fulfill our demand of pulse. We should give more attention to this protein source as the demand is close to 2 million tons but the country generates only 0.53 million tons comparing with total demand (Razzaque, 2000). Climate change is manifested by unpredictable rainfall patterns, further complicating the plight of farmers. There is a need to identify varieties that are adaptable to these challenges. As pigeon pea can be grown with relative ease and growing it can uplift farmers' livelihoods especially of it's wide range of adaptability with low cultivation cost and little management practices which also makes it a good crop for helping farmers adapt to climatic variability and change. If farmers select varieties are adaptable to their region they will plant the right varieties and will bring it under commercial cultivation as a result good yield would translate to better income leading to improved livelihoods. So, there is a need to identify suitable pigeon pea varieties for better yield with good carbon sequestration ability and also for make ensure the improvement of farmer's livelihoods. Considering above facts, the study was taken to evaluate the yield performance and carbon sequestration of pigeon pea in three studied areas Gazipur, Sylhet and Madaripur and to determine the stability performance of different pigeon pea.

2. Materials and Methods

The experiment was performed at the research field of Pulse Research sub-center (PRC) in Bangladesh Agricultural Research Institute (BARI), Gazipur; Regional Agricultural Research Station (RARS), Sylhet and also at Regional Pulses Research Station (RPRS), Madaripur during the period of September 2018 to May 2019.The Experimental materials comprised of four pigeon pea genotypes namely G1= BPP1502, G2 =BPP1503, G3 = BPP1504 and G4 = BPP1505 which were collected from Bangladesh Agricultural Research Institute (BARI) were used in the experiment. The experiment was consisted of two factors. Factor 1: Three locations:- a. BARI, Gazipur; b. RARS, Sylhet and c. RPRS, Madaripur ;Factor 2: Four pigeon pea genotypes.The experiment was laid out following the Randomized complete Block Design (RCBD) with three replications. Each treatment combination was replicated three times with plot size 3 rows × 3m and spacing 80 cm × 25 cm. The land was watered prior to ploughing. Then the land was first uncovered with tractor down disc plough. The soil which was ploughed was brought into suitable fine tilth by four ploughing and cross ploughing. harrowing and laddering. The stubble and weeds were moved from the land for the convenient germination of pigeon pea seedlings.The experimental land was divided into unit plots following the design of experiment. The plots were spaded one day before seed sowing and the basal dose of fertilizers was incorporated thoroughly with soil. At BARI, Gazipur, seeds were sown in rows on 29 September, 2018 and at RARS, Sylhet, seeds were sown on 27 November, 2018 and at RPRS, Madaripur on 1st October, 2018.The pigeon pea seeds were sown at about 3.4 cm depth from the surface of soil. Urea, triple super phosphate (TSP), Murate of potash (MOP) and Gypsum were used as source of nitrogen, phosphorus, potassium, Sulphur and boron respectively. Total amount of urea, TSP, MOP and Gypsum were applied at basal doses during final land preparation. The doses of TSP, MOP, Gypsum, Boron and urea were 25gm, 15gm, 2 gm and 25gm per meter square respectively. Weeding was done once in the entire unit plots with care so as to maintain a uniform plant population.

Thinning was done at 20 days after sowing (DAS) and 30 DAS.Irrigation was given to get the maximum germination percentage. During the whole experimental period, there was a heavier of rainfall in earlier part. So it was essential to remove the excess water from the field at later period.Little pest and disease management was taken. Autostin (2gm/ml) was sprayed after two month of sowing. Ten plants were selected randomly from each plot and were uprooted for data recording. The rest of the plants of prefixed per m^2 area were harvested plot wise and were bundled separately tagged and brought to the threshing floor. The collected data from the experiment were statistically analyzed following the analysis of variance techniques to obtain the level of significance by using R-STAT. The significant differences among the treatment means were compared by Least Significant Difference (LSD) at 5% levels of probability.

3. Results and discussion

3.1. Interaction effect of location and genotype on plant height (cm)

The interaction effect of location and genotypes of pigeon pea on plant height (cm) was varied significantly (Table 1). The maximum plant height (103.33 cm) was found in BPP1505 at BARI, Gazipur which was statistically different from others. It was recorded that the minimum plant height (50.66 cm) was observed in BPP1504 at RAPS, Sylhet which was statistically similar to Sylhet×BPP1502, Sylhet ×BPP1505 and Sylhet ×BPP1503 interaction.

Plant height was positively and significantly correlated with vegetative growth of pigeon pea. The increase in plant height was associated with prolonged plant growth period and increased vegetative growth, leading to production of taller plants. The significant influence of locations and cultivars on plant height (Table 1) was supported by the observation made by Egbe and Vange (2008), which showed that pigeon pea plant heights are affected by maturity duration, cultivars, and environments.

The variation of plant height may be due variation in mean temperature and also for availability of irrigation water. Plant height of pigeon pea was significantly affected by temperature with both mean maximum and mean minimum temperature (Kamau, 2013). These results suggested that supplementary irrigation increases the plant height in pigeon pea plants by an average of 34.4 cm (Khourgami *et al*., 2012). These results also support the findings of Rahman *et al.* (2016) who observed significant variation of plant height among different chickpea genotypes. The variation of plant height among the genotypes of pigeon pea might be due to different genetic makeup of the genotypes.

3.2. Interaction effect of location and genotype on plant breadth (cm)

Significant variation of interaction was observed on plant breadth (cm) between genotypes of pigeon pea and location (Table 1). The highest plant breadth (64.5 cm) was obtained from BPP1505 at Madaripur which was statistically similar to the interaction Madaripur ×BPP1504 and Madaripur × BPP1503. The result was revealed that the lowest plant breadth (26.33cm) was found from BPP1503 at Sylhet which was followed by the interaction Sylhet ×BPP1502, Sylhet ×BPP1504 and Sylhet ×BPP1505.

Lower plant breadth may be due to poor growth during the days of plant maturity. The days to plant maturity was significantly and positively correlated to plant height, pod length and pod width (David *et al*., 2016).

Studies conducted by Sreelakshmi *et al*. (2010), Sodavadiya *et al*. (2009), and Vijayalakshmi *et al*. (2013) on pigeon pea have reported significant positive correlations between duration to flower development and plant maturity and plant height, pod length and width, as well as primary and secondary branches of the plants.

3.3. Interaction effect of location and genotype on stem diameter

The interaction effect on stem diameter (cm) between location and genotypes was observed significant (Table 1). It was obtained that the highest stem diameter (5.83cm) was found at Gazipur in BPP1505 was followed by the interaction Madaripur×BPP1505, Gazipur ×BPP1502 and Gazipur ×BPP1504. The lowest stem diameter (3.83 cm) was recorded at Sylhet in BPP1504 which was followed by the interaction Sylhet ×BPP1503 and Sylhet ×1502.Mean temperature is critical during the vegetative phase of growth of pigeon pea variation in stem diameter might be environmental factors. Wet soil due to frequent rain in growth phase cause poor stem growth of plant as well as plant growth.

3.4. Interaction effect of location and genotype on number of branches plant^{-1}

Significant variation of interaction was observed on number of branches plant^{-1} between location and genotypes of pigeon pea (Table 1). It was noted that the highest number of branches plant^{-1} (13.00) was obtained from the interaction, Gazipur×BPP1505 which was statistically identical with the interaction, Gazipur ×BPP1503 (12.33) and Gazipur ×BPP1502 (12.00). The lowest number of branches plant^{-1} (5.66) was found from the interaction, Madaripur×BPP1505 which was statistically similar with the remaining interaction except the interaction, Gazipur ×BPP1504 (11.00).

The duration to plant maturity was positively and significantly correlated to flower formation, plant height, pod width and primary and secondary branches ((David *et al*., 2016). Positive and significant correlations of pigeon pea branches with plant height have also been reported (Vijayalakshmi *et al*., 2013).

There are positive correlations between plant height and crop yield during the ratoon season could be as a result of increases in the foliage (number of leaves) and production of more branches, leading to greater production of pods. These traits (plant height, leaves, and branches) seem to function in tandem with one another in soybean (*Glycine max*) and this may influence pigeon pea in a similar manner (Udensi *et al*., 2010). Quddus *et al* (2014) stated that the soil of different part of southern belt in Bangladesh are more or less deficient in Boron and Zinc as well as Nitrogen fixing Bacteria (*Rhizobium* sp.) which are main cause of poor yield.

Table 1 Interaction effect of location and genotype of pigeon pea on plant height(cm), plant breadth(cm), stem diameter/plant (cm) and number of branches/plant

Treatment combination	Plant height (cm)	Plant breadth (cm)	Stem diameter plant^{-1} (cm)	Number of branches plant^{-1}
Gazipur × BPP1505	103.33333 a	50.66667 c	5.833333 a	13.000 a
Gazipur × BPP1502	91.33333 b	47.00000 c	5.066667 ab	12.000 ab
Gazipur × BPP1504	91.00000 b	51.33333 bc	5.000000 ab	11.000 b
Gazipur × BPP1503	86.66667 bc	45.66667 c	4.566667 bc	12.333 ab
Madaripur × BPP1505	78.33333 cd	64.50000 a	5.100000 ab	5.666 c
Madaripur × BPP1502	72.16667 d	59.58333 a	4.500000 bc	5.666 c
Madaripur × BPP1504	70.83333 d	61.08333 a	4.416667 bc	6.333 c
Madaripur × BPP1503	70.33333 d	58.00000 ab	4.300000 bc	6.000 c
Sylhet × BPP1503	54.00000 e	26.33333 d	4.033333 c	6.000 c
Sylhet × BPP1505	53.33333 e	31.00000 d	4.366667 bc	5.666 c

Sylhet × BPP1504	53.00000 e	31.00000 d	3.933333 c	6.333 c
Sylhet × BPP1502	50.66667 e	30.33333 d	3.833333 c	5.666 c
CV%	9.492	9.013	11.085	14.230

3.5. Interaction effect of location and genotype on number of pods plant^{-1}

The number of pods is the most important yield contributing character in pigeon pea. The highest number of pods usually leads to higher grain yield and vice versa.

Significant interaction was noted on number of pods plant^{-1} between location and genotypes of pigeon pea (Table 2). Results verified that the highest number of pods plant^{-1} (188.00) was obtained from the interaction, Gazipur×BPP1504 which was statistically close to the interaction Gazipur ×BPP1503 (161.33), Gazipur × BPP1505 (159.33) and Gazipur ×BPP1502 (153.33). On the other hands the lowest number of pods plant^{-1} (71.66) was recorded from the interaction, Sylhet×BPP1505 which was statistically close to the interaction Sylhet ×BPP1502, Sylhet ×BPP1503.

The presence of elevated temperatures during flowering period may result in flower shedding, drop of immature pods as well as inhibition of flower and pod settings. This phenomenon is similar to that reported in broad bean (*Vicia faba*) in which fewer pods per plan were recorded under elevated temperature conditions (Manzer *et al*., 2015).

The results are in agreement with the findings of Rahman *et al.* (2015) who observed the significant variation on the number of pods per plant in lentil at different location in Bangladesh

Delay sowing of pigeon pea affects the vegetative growth and exposes the plant to high temperature during reproductive phase. Therefore, the immature pods are dropped (MoEF and CC, India).

3.6. Interaction effect of location and genotype on number of seeds pod^{-1}

The interaction effect on number of seeds pod^{-1} between genotypes of pigeon pea and location was found significant (Table 2).From the table it was observed that the highest number of seeds pod^{-1}(4.33) was obtained from the interaction, Gazipur×BPP1505 which was statistically similar with the interaction Sylhet×BPP1504 and Madaripur×BPP1504 and the lowest number of pods^{-1} (3.50) was found from the interaction Sylhet×BPP1503 which was statistically closed to Madaripur×BPP1503 and Gazipur×BPP1502.

Increases in mean temperatures during the flowering and pod development phases of plant growth affected many of the yield variables for experiments at different locations (David *et al.,* 2016).

The primary branches were correlated to secondary branches and seed per pod during crop season. Pigeon pea is very sensitive to low radiation at flowering and pod development. Therefore, flowering during the monsoon and cloudy weather lead to bud drop and poor pod formation. (MoEF and CC, India) which causes lower seeds in pod.

3.7. Interaction effect of location and genotype hundred seed weight (gm)

Size and weight of seed is an important trait which directly correlates with final grain yield. The size of grains differs under different soil moisture regimes and under nutrient availability to crop. The genotypes producing larger seed size do not necessarily produce higher yields because of less in quantity.

Hundred seed weight (gm) was also varied significantly between the interaction of genotypes of pigeon pea and location (Table 2). The highest 100 seed weight was observed in BPP1504(9.10g) at Gazipur was similar to BPP1505(8.53) at Gazipur also. The lowest value (5.16g) was recorded in BPP1503 at Sylhet.

Both primary and secondary branches were also shown to increase seed weight and number of seeds per pod at both locations during the crop season. This indicates that under favorable conditions, high number of branches may lead to increased seed weight and seed per pod. Similar results have also been reported by other authors (Bharathi and Saxena, 2013; Saleem *et al*., 2005).

Agronomic practice like plant population is known to affect crop environment, which influence the yield and yield components. Optimum population levels should be maintained to exploit maximum natural resources such as nutrient, sunlight, soil moisture and to ensure satisfactory yield (Sharifi *et al.,* 2009). If plant population is lower than optimum, then per hectare production will be low and weeds will also be more (Allard, 1999). Plant population plays an important role in pigeon pea production and its response to varied population levels due to its elastic nature in adjusting to different spacing.

3.8. Interaction effect of location and genotype on carbon dioxide sequestration plant^{-1} (Ibs)

The sequestration of carbon depends on plant height, plant breadth and stem diameter. Therefore, variation of carbon sequestration by pigeon pea might be due to variation of those following factors.

The interaction effect of location and genotypes of pigeon pea on carbon dioxide sequestration plant^{-1} (Ibs) was varied significantly (Table 2). The maximum amount of carbon dioxide sequestration plant^{-1} (7.633 Ibs) was found in BPP1505 at BARI, Gazipur which was statistically close to BPP1504 and BPP1502 at the same location and different from other interaction. It was recorded that the minimum amount of carbon dioxide sequestration plant^{-1} (1.566 Ibs) was observed in BPP1503 at RARS, Sylhet which was statistically similar to Sylhet×BPP1502 interaction.

3.9. Interaction effect of location and genotype on carbon dioxide sequestration year^{-1} (Ibs)

The interaction effect of location and genotypes of pigeon pea on carbon dioxide sequestration year^{-1} (Ibs) was varied significantly (table 2). The maximum amount of carbon dioxide sequestration year^{-1} (15.233 Ibs) was found in BPP1505 at Gazipur which was statistically different from other interaction. It was recorded that the minimum amount of carbon dioxide sequestration year^{-1} (3.100 Ibs) was observed in BPP1503 at Sylhet which was statistically similar to Sylhet×BPP1502 interaction.

This might be due to sowing season. September is the optimum time for post rainy season sowing. At Gazipur, pigeon pea plants are sowing in September which causes better growth and development and delay sowing (last of November) at Sylhet causes poor growth of plants.

Table 2 Interaction effect of location and genotypes of pigeon pea on number of pods/plant, number of seeds/pod, hundred seed weight (gm), carbon dioxide sequestration/plant (lbs) and carbon dioxide sequestration/year (lbs)

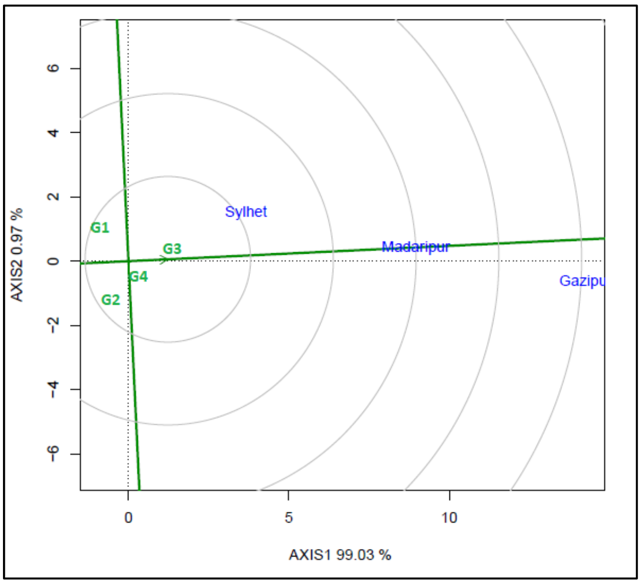
Treatment combination	**Number of pods/plant**	**Number of seeds pod^{-1}**	**Hundred seed weight (gm)**	**CO_2 sequestration/Plant (Ibs)**	**CO_2 sequestration/year(Ibs)**
Gazipur × BPP1504	188.000 a	4.233 ab	9.100 a	5.000000 b	9.966667 b
Gazipur × BPP1503	161.333 ab	4.133 abc	7.266 cd	4.033333 bc	8.066667 bc
Gazipur × BPP1505	159.333 ab	4.333 a	8.533 ab	7.633333 a	15.233333 a
Gazipur × BPP1502	153.333 abc	3.833 cd	6.766 de	5.000000 b	10.000000 b
Madaripur×BPP1504	135.666 bc	4.250 a	7.766 bc	3.283333 bcd	6.533333 bcd
Madaripur×BPP1503	118.833 cd	3.816 cd	6.216 e	3.083333 bcd	6.183333 bcd
Madaripur×BPP1505	115.500 cde	4.150 abc	7.333 cd	5.000000 b	9.933333 b
Madaripur×BPP1502	114.500 cde	3.850 cd	6.466 de	3.383333 bcd	6.766667 bcd
Sylhet × BPP1504	83.333def	4.266 a	6.433 de	2.133333 cd	4.300000 cd
Sylhet × BPP1503	76.333 ef	3.500 d	5.166 f	1.566667 d	3.100000 d
Sylhet ×BPP1502	75.666 ef	3.866 bcd	6.166 e	1.766667 d	3.533333 d
Sylhet × BPP1505	71.666 f	3.966 abc	6.133 e	2.366667 cd	4.633333 cd
CV%	**19.412**	**5.533**	**7.964**	**30.561**	**30.659**

3.10. GGE biplot

The GGE biplot was constructed by plotting the primary effect scores of each genotype and each environment against their respective secondary scores. Biplots can be used to evaluate specific cultivars in specific environments; the environment centered the yield approximated by the product of the genotypic PC1 score and the environment PC1 score, plus the product of the genotypic PC2 score and the environment PC2 score.

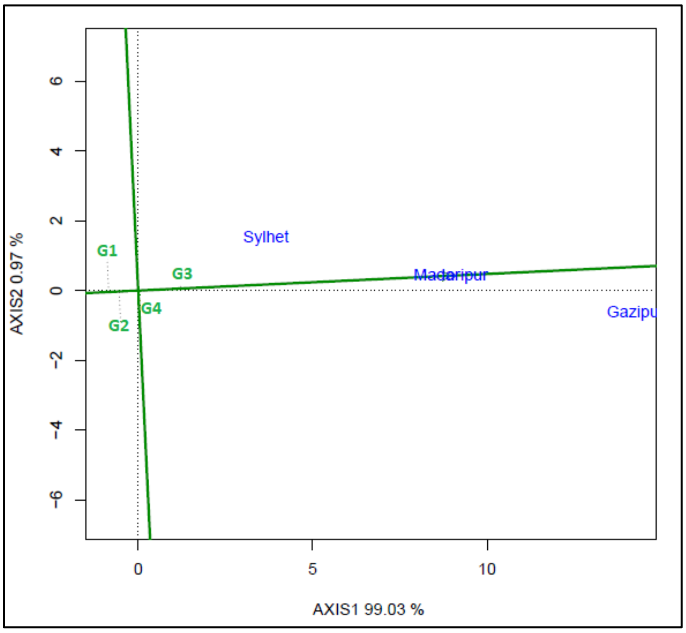
3.11. Ranking ideal genotype of pigeon pea for yield

Ranking genotypes relative to ideal genotype of pigeon pea, a genotype is more desirable if it is situated closer to the ideal genotypes. Concentric circles were drawn to help visualize distance between each genotype and ideal genotype by using the ideal genotype as the center. Figure 1 revealed that BPP1504 and BPP1505 were felled into the center of concentric circles, ideal genotypes in terms of higher yielding ability and stability, compared with the rest of the genotypes.Kaya *et al.* (2006) reported similar results in case of ranking genotypes different varieties of wheat.



G1=BPP1502, G2=1503, G3=BPP1504 and G4=BPP1505

Figure 1 Ranking of ideal genotype of pigeon pea for yield Mean vs stability performance for yield of pigeon pea



G1=BPP1502, G2=1503, G3=BPP1504 and G4=BPP1505

Figure 2 GGE-biplot showing the ranking of pigeon pea genotypes for both mean performance and stability over environments

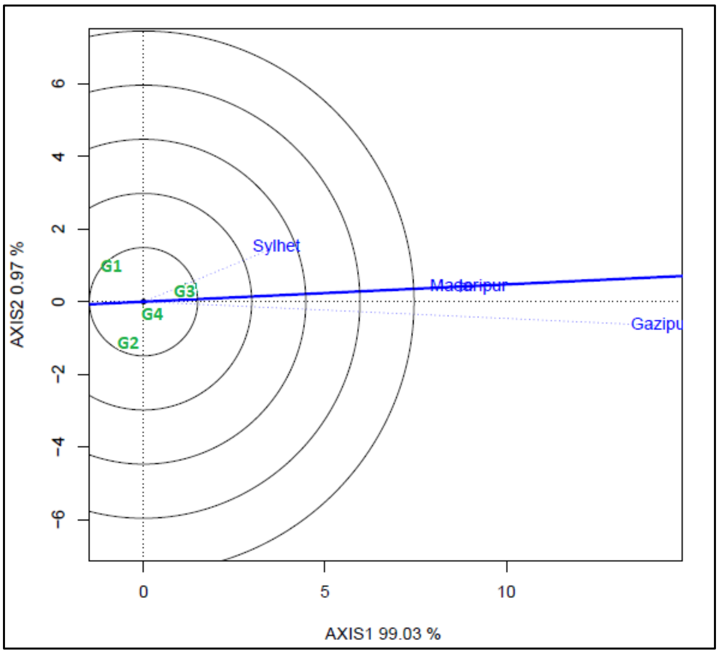
Based on Figure 2, it is possible to assess both mean yield and stability performance of pigeon pea through a biplot. An average tester coordinate (ATC) horizontal axis was passed through the biplot origin and the average location and the oval was shown the positive end of the ATC horizontal axis. The average yields of genotypes were determined by projections of their markers on to the ATC horizontal axis. Therefore, it was found that the genotype of pigeon pea, BPP1504 had the highest average yield and the BPP1503 the lowest (figure 2).

Increases in mean temperatures during the flowering phase in vegetable pigeon pea may lead to reduction in the duration to flowering, maturity, and plant yield. This finding is supported by Prasad *et al*. (2003) who observed that decreased number of fruit set at higher temperature was mainly due to poor pollen viability, reduced pollen production, and poor pollen tube growth, all of which lead to poor fertilization of flowers in peanuts. Wang *et al*. (2006) associated grain yield reduction to reduced pollen viability, reduced number of seeds per plant and weight per seed in chickpea (*Cicer arietinum*).

Stability of each genotype was explored by its projection onto the ATC vertical axis. The smaller the absolute length of projection of a genotype, the more stable it is. Thus, it recorded that genotype BPP1502 and BPP1503 were the least stable and genotypes BPP1504 and BPP1505 the most stable. Therefore, considering both mean yield and stability performance, genotypes BPP1504 following to BPP1505 could be regarded as the most favorable. The results obtained by Karimizadeh *et al.* (2003) was in agreement with findings of present study.

3.12. Discriminativeness vs representativeness of location for yield of pigeon pea

Discriminating ability and representativeness of the test environments can be measured as the absolute distance of an environment from the biplot origin and the length of the projection from the marker of an environment onto the ATC Y-axis was shown in Figure 3. Thus, environment of BARI, Gazipur was the best as it had small projection onto ATC Y-axis (representative of test environments) and large projection onto ATC X-axis (highly discriminating ability for genotypes).



G1=BPP1502, G2=1503, G3=BPP1504 and G4=BPP1505

Figure 3 The vector view of the GGE-biplot to show relationship among environments for yield of pigeon pea

The results obtained by Ullah *et al*. (2011) was in agreement with findings of present study.

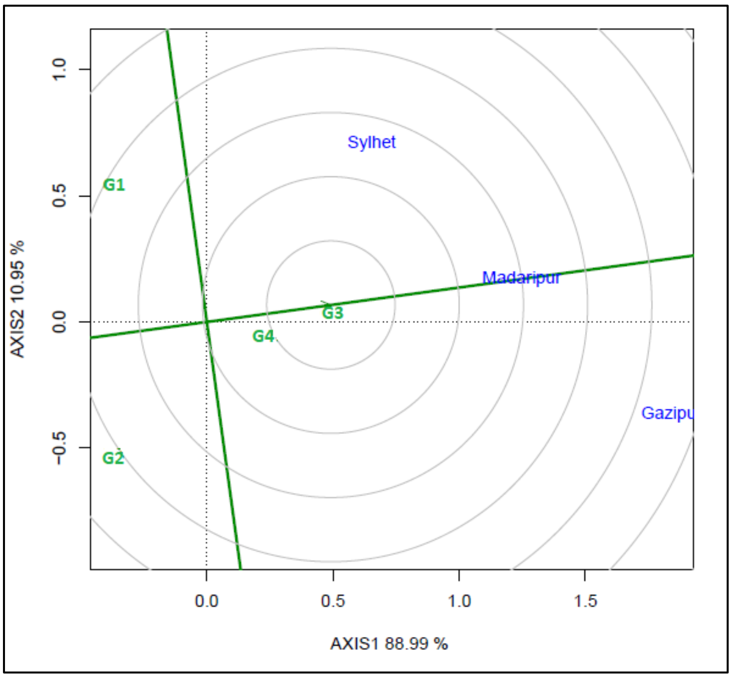
Another important measure of a test environment is its representativeness of the target environment. The bi-plot way of measuring representativeness is to define an average environment and use it as a reference. The angle between the vector of an environment and the ATC axis is a measure of the representativeness of the environment. Hence BARI, Gazipur was noted as most representative, whereas RARS, Sylhet as least representative of the average environment.

Nazrul *et al.* (2012) conducted an experiment and reported in Sylhet region, vast areas of lands remain fallow during Rabi season in each year because, soil moisture goes down quickly after harvest of T. aman rice and due to lack of irrigation facilities under the present circumstances, the system of single and double cropping has failed.

Fallow-T. aus-T. aman rice is the dominant cropping pattern under rainfed condition in this region. The delayed transplantation of aus rice due to dependence on rainfall and usually transplanting is done in early May. This delayed transplantation of aus rice, hampered the timely cultivation of subsequent T. aman rice and resulting delay sowing of Rabi crops (Nazrul *et al*., 2015).

3.13. Ranking ideal genotype of pigeon pea for carbon dioxide sequestration

The genotypes have the highest mean performance and be absolutely stable (i.e. perform the best in all environment) is termed as ideal genotype. From the figure 4, it was observed that the genotype BPP1504 located at the center of the concentric circle was identified as the ideal genotype in terms of carbon dioxide sequestration among the other genotypes. The genotype, BPP1505 was located on the next concentric circle, regarded as desirable genotype for carbon dioxide sequestration. The rest genotypes situated at the fourth and fifth concentric circle were termed as undesirable and lower capacity for carbon dioxide sequestration.

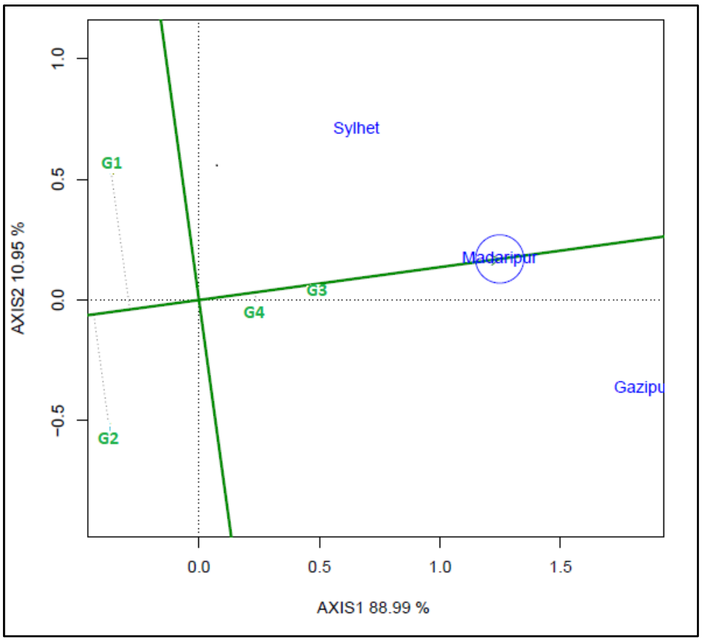


G1=BPP1502, G2=1503, G3=BPP1504 and G4=BPP1505

Figure 4 Ranking ideal genotype of pigeon pea for carbon dioxide Sequestration

3.14. Mean performance vs stability for carbon sequestration of pigeon pea

From the figure 5, it was obtained that the genotype of pigeon pea, BPP1504 had the highest value for carbon dioxide sequestration and BPP1503 the least value. It recorded that the genotype, BPP1504 was the most stable genotype for carbon dioxide sequestration.

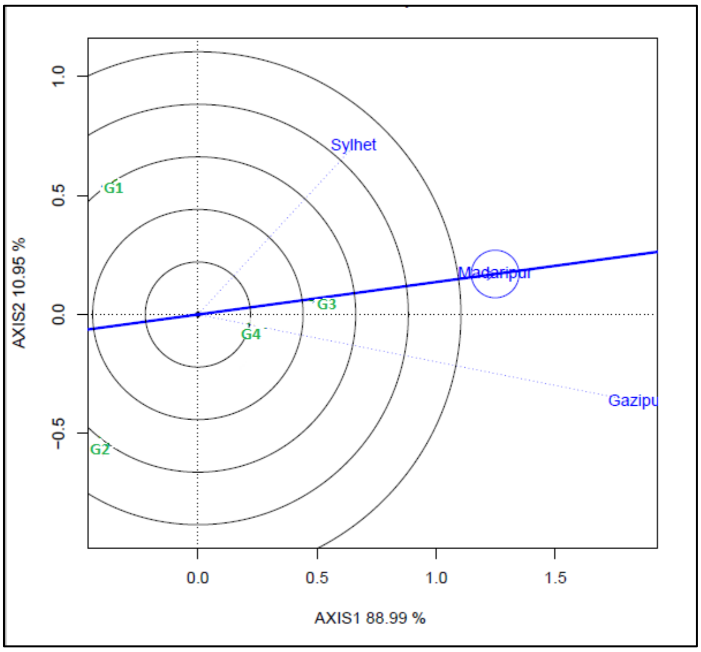


G1=BPP1502, G2=1503, G3=BPP1504 and G4=BPP1505

Figure 5 GGE-biplot showing the ranking of pigeon pea genotypes for both mean performance and stability over environments

4. Discriminativeness vs representativeness of location for carbon sequestration of pigeon pea

Another interesting observation from the vector view of the bi-plot is that the length of the environment vectors approximates the standard deviation within each environment, which is a measure of their discriminating ability (Yan and Kang, 2003). It was found that BARI, Gazipur was most discriminating as it had small projection onto ATC Y-axis (representative of test environments) and large projection onto ATC X-axis (highly discriminating ability for genotypes). RARS, Sylhet was least in terms of discriminativeness and representativeness (Figure 6).



G1=BPP1502, G2=1503, G3=BPP1504 and G4=BPP1505

Figure 6 The vector view of the GGE-biplot to show relationship among environments for carbon sequestration of pigeon pea

5. Conclusion

According to the experimental results, it was estimated that the genotype BPP1504 had the highest average yield and the BPP1503 had the lowest. The environment of BARI, Gazipur was found as the best (representative of test environments and highly discriminating ability for genotypes). Considering both mean yield and stability performance, genotype BPP1504 following to BPP1505 of pigeon pea could be regarded as the most favorable for any location. Therefore, the highest value for carbon sequestration of pigeon pea was identified from the genotype BPP1505.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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